Special Article

Methods Used to Interpret the 12-Lead Electrocardiogram: Pattern Memorization versus the Use of Vector Concepts

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Summary: This article extols the value of using Grant's approach to the interpretation of electrocardiograms (ECGs). The essay includes a discussion on how people learn and emphasizes the difference in memorizing information, thinking, and learning. Simply stated, the brains of most people are not designed to memorize countless numbers of ECG patterns. Accordingly, the essay supports the view that a method of interpretation must be used, and the reader is encouraged to use basic principles of electrocardiography, including vector concepts, to interpret each ECG.

Key words: memorizing, thinking, learning, basic principles, vector concepts, interpreting electrocardiograms, Grant

Introduction

This essay seems justified because there is considerable anecdotal evidence indicating that the interpretation of electrocardiograms (ECGs) has deteriorated to an unsatisfactory level. Despite this worrisome state, the recording of ECGs continues to be one of the most useful and commonly performed medical procedures.

A 12-lead ECG is recorded for two reasons: to identify the rhythm of the heart and to discover abnormalities of the car-

diac myocytes and conduction system that correlate with cardiac disease processes. This essay deals only with the analysis of the shape of the waves seen in the ECG; it does not address the method used to decipher cardiac arrhythmias.

Two methods are available to analyze the shapes of the complexes seen in the 12-lead ECG: the pattern memorization method and the method popularized by Robert Grant in which basic principles, including vector concepts, are used to analyze each tracing.[1-8] The purpose of this presentation is to emphasize the value of Grant's approach to the interpretation of each ECG.

An Example of the Problem

A cardiac fellow was struggling to interpret an ECG. He knew the rhythm was normal but could not imagine what was wrong with the P, QRS, S-T, and T waves. I tried to assist him by drawing a few arrows on the board. He looked a bit bewildered and said, "We did not use the vector method of interpretation in my previous training as a medical house officer." I was pleased that at least he knew what I was doing, but asked, "Oh, what method of interpretation *did* you use during your residency in internal medicine?" He came to a dead stop in his effort to explain his difficulty because, during his earlier training, he had tried to memorize the ECG patterns that were associated with cardiac disease. Because he had forgotten, or had not previously seen complexes that were shaped like the complexes noted in the tracing we were discussing, he could not interpret the tracing. He had no tools that enabled him to think. He knew no basic principles of electrocardiography. Accordingly, one could argue successfully that he actually had no method of interpreting ECGs. *A deeper concern was that he might not know how people learn.*

How People Learn

Nascent teachers, trainees, and practicing physicians must delve into the subject of learning how to learn, else they will confuse information, memorization, and thinking with learn-

ing.[9] A discussion of the mysterious mental action known as learning must begin with a definition of the words involved in the process.

How people learn is germane to the subject of electrocardiography because the complexes are viewed as objects that are registered in the brain. Accordingly, electrocardiography can serve as a model that enables an inquisitive person to gain insight into the learning process itself.

Information should be viewed as abstract objects that are discovered by the use of our five senses. We collect information by seeing, hearing, feeling, tasting, and smelling. The bits of information we discover using these senses are registered in different parts of the brain; they may or may not be stored for further use depending on our interest in them.

A nascent interpreter of ECGs sees waves in the ECG and relays the images to his or her brain. The interpreter then decides, rightly or wrongly, which images should be stored. Whether or not he or she is capable of storing the information for a designated period of time is another problem (see next section).

Memory can be defined as the storage of information in the brain. The duration of time the information remains stored in the brain varies considerably and the ability to recall it is unpredictable. How can an individual ensure that designated bits of information will remain stored in the brain for use when the need arises? Stated another way, how does an individual improve memory? This feat can be accomplished by combining two mechanisms; an individual can use the bits of information frequently and can link the new information to a memory that was previously stored in the brain and that is used frequently.[10] Once this approach is appreciated, an individual who wishes to improve memory develops the habit of sensing something and then searching the brain for a context to which the new information can be linked.

We improve our memory of ECG images by viewing large numbers of ECGs and by linking what we see to commonly used basic principles of electrocardiography, including vector concepts, that have been previously stored in the brain.

Thinking is the manipulation of information that is stored in the brain.[9, 11, 12] It is the reorganization of information into a new perception for the person doing the rearranging. Rita Carter said it beautifully in her book *Mapping the Mind*. She wrote: "The nuts and bolts of thinking—holding ideas in mind and manipulating them—takes place in a region of cortex on the dorsolateral (upper side) prefrontal cortex."[13]

Thinking is a cognitive skill that can be consciously pursued and can be taught. Much information is needed to help us get through a day, but all of the information we gather is not necessarily used in thought processes. We filter out information we believe we do not need or do not understand. We look up the telephone number of an individual with whom we wish to talk. If we use the number only once we will undoubtedly forget it. If we use it ten times we might remember it, but only if we decide it will be less trouble to do so. Someone might stretch the definition of thinking to include this action, but I chose not to do so because there has been no rearrangement of images in the brain.

Each part of the P wave, QRS complex, ST segment, and T wave of the ECG should stimulate the recall of a series of images that are already stored in the brain. When there are no images there is no thinking, and understanding falters (see later discussion).

Learning is even more complex than gathering information or thinking. Learning is accomplished by the repeated implementation of a skill. The sluggish use of a skill does not guarantee that the individual has learned the skill; it only means that the person knows about the skill. For example, a person might be able to press the correct letters on a typewriter, but might require an hour to type a paragraph. Although the paragraph may be word-perfect, one who types that slowly cannot claim to be proficient in typewriting and has not developed fluency. When that person is removed from typewriting for a year, that poor typing skill will deteriorate considerably and much time and effort will be needed to develop proficiency. The individual who can type the same paragraph in two minutes is fluent. The speed indicates that the person has practiced, and practiced until fluent.[14] Removed from typewriting for a prolonged period of time, such a person will be a bit sluggish when the task is tried again, but after a short period of practice will perform at the former rapid rate.

Suppose an individual takes 20 minutes to interpret an ECG. Without contact with ECGs for several weeks or months, he or she may be unable to interpret them. This failure is predictable because the individual did not learn to interpret ECGs in the first place and was never fluent in the interpretation of tracings. If, however, one can interpret an ECG correctly in a minute, that person has become fluent. This signifies that the individual has practiced, and practiced, and practiced. Seeing no ECGs for weeks or months, then challenged to interpret tracings again, he or she will be a bit sluggish at the beginning but will be back to the former state of competence in a short time. Such an individual is fluent in the interpretation of ECGs and can be designated as one who has *learned* to interpret them.

Why the Memory System Is Difficult to Master

Many individuals have trouble memorizing a large number of different ECG patterns. I have shown the same ECG to highly intelligent trainees in cardiology as many as three or four times within a few months and have found that many of them do not recall having seen the tracing previously. I assure them there is nothing wrong with their brains; they are simply trying to make their brains do something that is very difficult, or impossible, for their brains to do.

Perhaps, like many other people, the trainees mentioned above were looking for a shortcut to learning to interpret ECGs—not an uncommon hope. In fact, books are written on shortcuts to interpreting ECGs. The sooner one accepts that there is no shortcut to learning to interpret ECGs, the sooner the learning process can begin. That the trainees could not remember a tracing shown to them on several previous occasions emphasizes that the two mechanisms used to improve

their memories had not been used. They did not use the information found in the tracing often enough to recall the interpretation and failed to link their observations to commonly used basic principles that should have been stored in their brains. Unfortunately, such failure is commonly due to the fact that many trainees have never stored the basic principles of electrocardiography, including vector concepts, in their brains. One could make a case that, if the trainees must memorize, they should memorize basic principles and how to use them in a thought process rather than trying to memorize the deflection they see.

Some observers assume they have interpreted the tracing when they proclaim, for example, that the T waves are inverted in leads I, V_5, and V_6. Such a proclamation is simply the gathering of information and does not indicate that thinking has occurred. Some people have trouble accepting that carefully selected bits of information are building blocks for thought processes; they often believe, albeit subconsciously, that the discovery of information is, itself, thinking. Such a belief—the inability to distinguish information from the thinking process—plays havoc with the learning curve.

Our hopes were high when computerized interpretation of ECGs was introduced several decades ago. We naively thought the computer would teach trainees, who were eager to learn. Our hopes were dashed when it became obvious that computers are poor teachers; they simply make information available for possible use. Even worse, the information offered by the computer is incorrect about 20 percent of the time. Still worse, the computer may not help the clinician because it never gives a differential diagnosis indicating the cardiac diseases that might be responsible for the abnormalities found in the ECG tracings. In addition, computer software is commonly outdated and modern views may not be expressed by the outdated machine. Stated another way, computers do not read journals or go to postgraduate courses. Neither do they learn from experience; they commonly make the same mistakes over and over again because they cannot correlate the ECG diagnosis with other clinical information. They are also guilty of rendering two different "interpretations" of tracings that are made only a few minutes apart on the same patient.

Some computers write out the frontal plane direction of the electrical forces responsible for the inscription of the mean P, QRS, and T waves. Unfortunately, the computer makes many errors in its effort to accomplish this, and is never able to determine the anterior and posterior direction of the electrical forces. If the physician who is assigned to "over read" the computer's interpretation is a memorizer, he or she either ignores or accepts the erroneous measurements made by the computer.

The computer interpretation of ECGs has abetted the notion that trainees can simply look at the computer readout rather than trying to understand the mechanisms responsible for the ECG abnormalities. This presumption is, of course, a serious impediment to learning. Such an approach invariably leads to a state of affairs in which the tracing is recorded and charged for, but ignored. When this occurs, the "interpreter" has entered the dangerous world of pretending.

How to Check the Memory System

One way to check the depth of knowledge of those who interpret ECGs using the memory system is to have them teach a group of trainees who have no knowledge of electrocardiography. The nascent teacher who is a memorizer may display a number of common ECG patterns to the trainees. That, of course, is not teaching; it is simply the transfer of information. The trainees may believe they are doing well because, for a brief period of time, they may be able to interpret a goodly number of tracings. To determine whether the trainees gained anything from the exercise, the "teacher" should ask them to interpret ECGs a few months later. They and the "teacher" will be shocked because the forgetting curve of the trainees will have overtaken their learning curve. There is nothing wrong with the brains of the "teacher" or the trainees; they simply have not realized that such an approach to teaching and learning is rarely successful.

To demonstrate the problem of memorizing without thinking, I often begin a teaching session by asking the small group of trainees to multiply 6 times 8 or 9 times 7. They, of course, have no trouble multiplying single digits. I then ask them to multiply 23 times 71. They have more trouble multiplying when the numbers are double digits. I then ask them to use pencil and paper to achieve the multiplication of 23 times 71. They, of course, have no difficulty doing something with the numbers to come up with an answer of 1,633. I then ask them to analyze why they could multiply single digits "in their head" and why they used pencil and paper to obtain the answer when they multiplied the two double digit numbers. We were all exposed to the multiplication tables in our early years of schooling. Our teachers keep at it; they worked with us until we could multiply single digit numbers through the number 9. The brilliant people, who lived centuries and centuries ago and taught those who followed them to use numbers recognized that the human brain could memorize the multiplication of single digits through 9, but had more difficulty with numbers beyond that. They also recognized that any double digit number consisting of a digit followed by a zero was also easy to use, and thus the number 10 was included in the multiplication tables. So, as handed down to us, we memorized the multiplication tables through the number 10. Later we were introduced to a method of multiplying double and triple digits. To accomplish the act we used a *system* of multiplying that reduced the double or triple digits back to single digits. Accordingly, we were not asked to memorize the multiplication of numbers that were larger than 10; when we needed to multiply double and triple digits we were taught to use a system.

How does this metaphor relate to the problem of interpreting ECGs? We can memorize a certain number of ECG abnormalities just as we memorized the multiplication tables through the number 10. Beyond memorizing a limited number of ECG patterns, however, we must have a system of analysis, just as we developed a system of multiplying double digits. The system we mastered with numbers is a multiplication system. The system we must master in electrocardiography is a system that uses basic principles, including vector concepts,

to interpret each ECG. It is useful to ponder the fact that there are more numbers to multiple beyond the limit of 10 than there are up to 10. There are also more ECG patterns to analyze that are outside the limits of anyone's memory system than within it. Accordingly, it seems wise to learn a system to interpret ECGs.

The Solution

It is, I believe, necessary to teach commonly used basic principles of electrocardiography, which include vector concepts, to understand the electrical forces responsible for the shape of the complexes. Furthermore, the concepts must be applied to every tracing over and over again until fluency is achieved. This not only requires practice on the part of the one trying to learn, but also requires feedback to a true teacher to judge whether learning has indeed occurred. When possible, the educational feedback loop should be checked months after the trainee and teacher part company.

In Defense of Commonly Used Basic Principles and Measurements

Most medical students hear at least one professor declare, "Scientific thinking usually begins when you can measure the things you are studying." This aphorism, commonly ignored, is a hand-me-down from the influential voice of William Thompson, Lord Kelvin, the brilliant English scientist, who stated the following:

> When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science.

Popular Lectures and Addresses (1891–1894)

If it seems that Lord Kelvin made a reasonable point, one might want to bring a system of measurement to the interpretation of ECGs. Realizing that it would be a formidable task to memorize the incalculable number of abnormalities of every part of the P, QRS, ST, T, and U waves in 12 leads, one might wonder whether the vector approach, which is a system of measurement, used primitively by Waller and Einthoven, enhanced by Frank Wilson[15, 16] and Robert Bayley,[17] and brought toward perfection by Robert Grant,[1, 2] might be used to measure the direction and size of the electrical forces of the heart.

Frank Wilson was a master of the science and art of electrocardiography. He wrote the following in the foreword of Barker's book in 1952. He was, without argument, a wise man.

> It is also desirable to master the more simple physical principles necessary to the understanding of how the

electrocardiograph operates and how the cardiac voltages which this instrument measures are produced and distributed throughout the body. Without this understanding electrocardiography becomes a mere collection of unrelated facts which burden the memory and stifle the intellectual interest without which learning is a chore instead of a pleasure....

...the interpretation of the electrocardiogram is not merely a matter of memorizing a few characteristic pictures; there are many unusual variations and combinations of electrocardiographic phenomena which must be studied, analyzed, and correlated one with another and with other available data before any definite conclusion is possible. These situations demand some acquaintance with the electrical and physiologic principles by which they are determined.[18]

Most excellent physicians believe it is wise to understand the pathophysiology of congestive heart failure, cardiac shock, angina pectoris, and so forth. Today, it would be inexcusable for a cardiologist not to know the molecular biology and pathophysiology associated with an atheromatous plaque located in a coronary artery. It therefore seems strange that the same physicians may not use the basic principles of electrocardiography to interpret ECGs.

Patterns Thought to Be Similar May Be Caused by Many Different Abnormalities

Whereas hundreds of examples could be used to illustrate the subject being discussed, only one will be presented here (see Figs. 1 and 2). An interpreter wrote: "The S-T segments are *elevated* in the inferior leads." An early learner might wonder whether the interpreter meant that some leads were better than others and that the leads where the abnormalities were noted were not very good leads. The interpreter might or might not understand why the S-T segments were elevated in the leads mentioned. This parenthetical remark is added to indicate that one reason the teaching of electrocardiography has deteriorated is that nonscientific jargon has, to an alarming degree, replaced scientific languages in our day-to-day conversation. Phrases such as "left ventricular strain" are commonly used even though they were deemed improper decades ago.

When the S-T segments are elevated in leads II, III, and aVF, many memorizers pay little attention to the S-T segment displacement always present in the other extremity leads as well as in the chest leads, while other interpreters may postulate that something else must be "going on" in the heart to account for the S-T segment displacement in the other leads. This, of course, indicates that they do not believe, or do not understand, or do not use Einthoven's law, which states that the deflections seen on lead I plus the deflection seen in lead III, equal the deflection seen in lead II. Furthermore, memorizers do not always appreciate that all electrical forces are spatially oriented; that is, they are directed anteriorly or posteriorly as well as to the right or left and up or down.
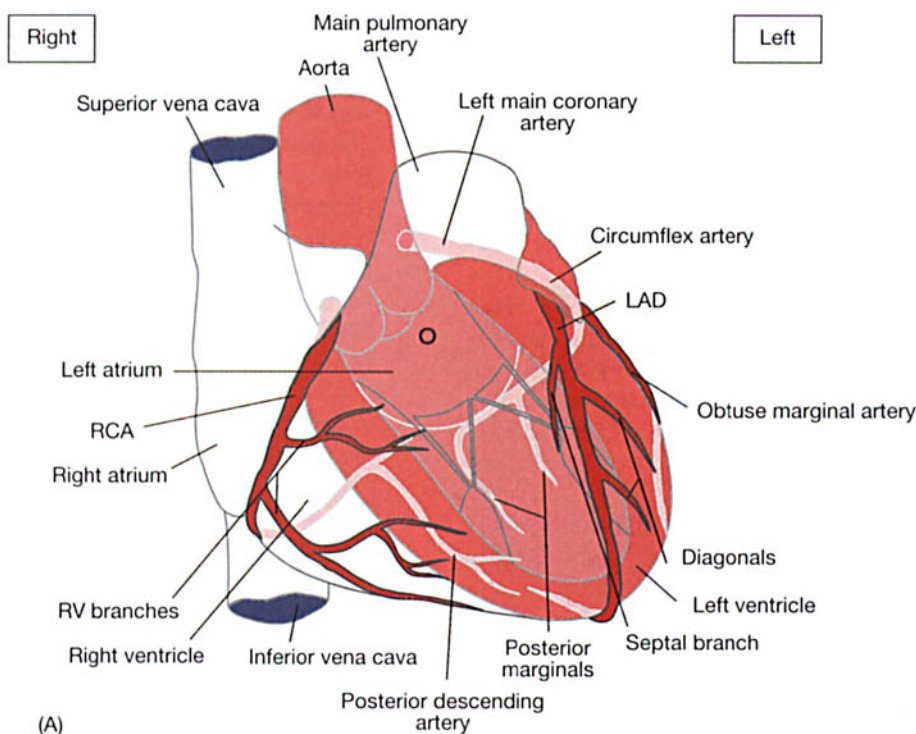
FIG. 1 (A) This figure illustrates the frontal plane view of the heart and the coronary arteries. The diagram is an approximation of the facts because it is not possible to display accurately a three-dimensional structure on a flat surface or to capture the anatomic variation that exists among individuals.

The coronary arteries that can be seen from the front are colored bright red. When the coronary arteries are located on the back of the heart or when they are covered by the pulmonary artery or atrial appendage they are colored pink.

To illustrate the anatomy of the left ventricle and coronary arteries, it was necessary to leave the right ventricle and right atrium uncolored, so they are white. The left anterior descending arteries lie in the groove location between the right and left ventricles. The blue color noted at the ends of the superior and inferior venae cavae suggests that the blood they deliver to the right atrium and right ventricle is unoxygenated. The right ventricle is obviously an anterior structure.

The left ventricle, shown in outline, the aorta, and the left atrial appendage are colored red. Note that the anatomic axis of the left ventricle is directed to the left and inferiorly. Transverse and lateral views of the heart reveal that the anatomic axis of the left ventricle is directed anteriorly and not posteriorly as is commonly believed. The reader should appreciate that the interventricular septum, which is not shown in the illustration, is also an anterior structure and forms a major part of the anterior portion of the left ventricle.

The inside of the left ventricle, including the aortic valve, is colored a shade of red that is in between red and pink. The body of the left atrium is shown as a circle. It is located posterior to the left ventricle in the center of the chest. It is not located on the left as the name implies. Hints of the anterior leaflet of the mitral valve and papillary muscles are also shown.

To simplify the diagram, the locations of the sinus node, atrioventricular node, His bundle, and the left and right ventricular conduction systems are not shown. However, the interpreter of electrocardiograms (ECGs) must visualize their spatial location.

To simplify the frontal plane view of the heart, the directions of normal depolarization and repolarization of the atria and ventricles are not shown. However, the interpreter of ECGs must visualize the spatial direction of the electrical forces created by these cardiac structures.

Different anatomic parts of the heart produce different electrical forces. Because the electrical potential varies inversely with the square of the distance, one can assume that most of the electrical forces originate at a common point in the center of the heart (note the small circle in the middle of the heart). This assumption is more accurate when applied to the extremity leads than when it is applied to the chest leads because the chest electrodes are located nearer the heart than the extremity leads. LAD = left anterior descending artery, RCA = right coronary artery, RV = right ventricular.

The fact is, elevation of the S-T segments in leads II, III, and aVF can be produced by a large number of differently directed electrical forces (see Fig. 1B). An inquisitive person might wonder whether a mean S-T segment vector that is directed at +90° in the frontal plane and produces elevation of the S-T segments in leads II, III, and aVF is caused by the same cardiac abnormalities that cause a mean S-T vector to be directed at +145° or at +35°, which also causes the S-T segments to be elevated in leads II, III, and aVF. Many who use the memory

method of interpretation cannot measure accurately the direction of the electrical forces of the heart and, because of this inability, may not detect important differences between tracings.

The Einthoven bipolar and Goldberger unipolar extremity leads record only the frontal plane view of electrical forces. The electrical forces are, of course, directed not only up or down, right or left, but anteriorly or posteriorly. To assume that electrical forces and the vectors used to represent them are two-dimensional is a serious conceptual error; all forces are
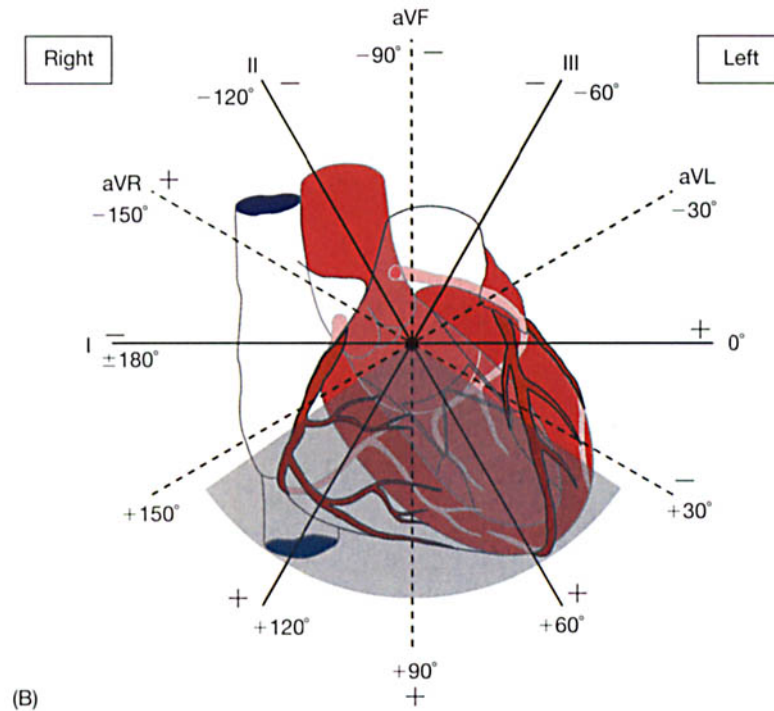
FIG. 1 (B) The hexaxial extremity lead system including leads I, II, III, aVR, aVL, and aVF is shown superimposed on the heart. When the S-T segment vector is directed between > + 30° to < +150, it will project positively on limb leads II, III, and aVF (see shaded area). Obviously, the exact direction of the S-T segment vector should be calculated using the Grant method of analysis,[4] because different directions of the S-T segment vector indicate different cardiac conditions. This diagram is incomplete because it only displays the frontal plane projection of the electrical forces responsible for the S-T segment displacement. It is always necessary to establish the anterior or posterior direction of the electrical forces as well as the frontal plane direction of electrical forces.[4]

three-dimensional. Grant not only taught us how to use the six extremity leads to determine the number of degrees electrical forces are directed to the right or left and up or down in the frontal plane, but he also taught us how to use the six unipolar chest leads of Wilson to estimate the approximate number of the degrees that electrical forces are directed anteriorly or posteriorly from the frontal plane.[1,2,4] Here, to illustrate the Grant approach, I am only discussing the displacement of the S-T segment. The interpreter must be able to determine the spatial direction of the electrical forces that produce the S-T segment elevations in leads II, III, and aVF because the exact direction of the spatially oriented mean S-T vector makes a great difference in the interpretation of the tracing.

With the foregoing in mind, Figures 2A, B, and C make several important points. Figure 2A shows the mean ST vector directed about + 145° in the frontal plane and 40° to 45° anteriorly, producing an elevated ST segment in leads II, III, and aVF. The S-T segment would be displaced downward in lead I and aVL and upward in lead aVR. The S-T segment would be displaced upward in leads V₁–V₃, and displaced downward in leads V₄–V₆.

The spatial direction of the S-T segment vector indicates epicardial injury associated with infarction of the inferior portion of the left ventricle with involvement of the right ventricle. Note that this is shown graphically in Figure 2A. Right ventricular infarction can be diagnosed if one remembers that the

right ventricle is an anterior structure and that the S-T segment vector is directed anteriorly toward epicardial injury located in the right ventricle. The memorizer, noting the S-T segment elevation in leads V₁–V₃, commonly misdiagnoses the condition as an anterior infarction.

Such an abnormality may be caused by acute coronary occlusion of the right coronary artery that is located proximal to its right ventricular branches. Note in Figure 2A that the vector representing the S-T segment points toward that portion of the right coronary artery. The farther the S-T vector is directed to the right and the more it is directed anteriorly in a patient with inferior infarction, the more likely the right ventricle is infarcted.[19,20]

Figure 2B shows an S-T segment vector that is directed at 90° in the frontal plane and about 30° posteriorly. The S-T segment will be elevated in leads II, III, and aVF, reminiscent of the S-T segment displacement produced by the S-T vector shown in Figure 2A. Memorizers may not detect the difference that exists in the extremity leads of the two examples because they do not measure the abnormalities. When the vector representing the S-T segment elevation is drawn, it is easy to see the difference in Figure 2A and B. The S-T segment will be isoelectric in lead I; elevated in leads II, III, and aVF; and displaced downward in leads aVL and aVR. In addition, the S-T segment vector is directed posteriorly, producing downward displacement of the S-T segment leads V₁–V₃ and S-T segments that are displaced upward in leads V₄, V₅, and V₆.
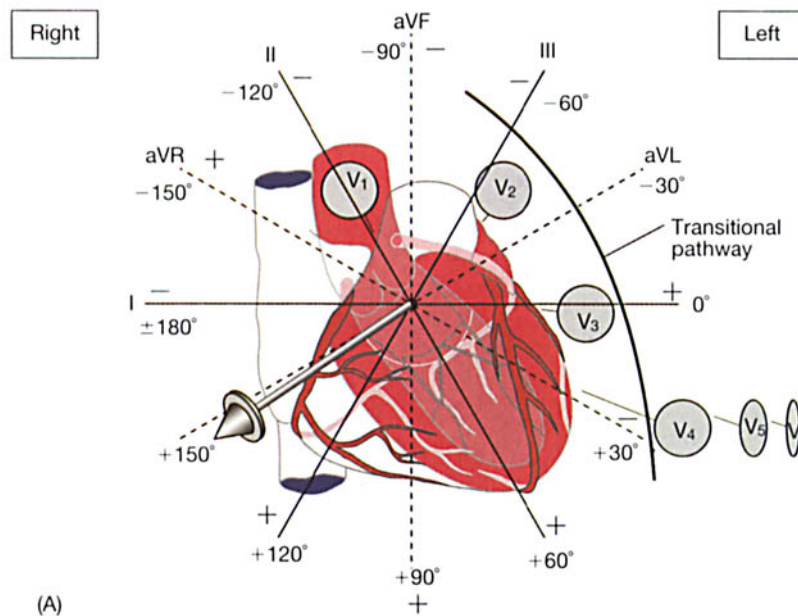
(A)

FIG. 2   The three parts of this figure (A, B, C) illustrate three electrocardiograms that all show S-T segment elevation in leads II, III, and aVF. Note that the locations of the precordial electrodes are shown as six gray circles labeled V_1–V_6. They are used to determine the anterior or posterior direction of electrical forces.[4] Note the line labeled *transitional pathway*: it is used to determine the anterior or posterior direction of electrical forces.[4] Figures A, B, and C illustrate how, using Grant's method of analysis,[4] the calculation of the spatial direction of the S-T segment vector enables the interpreter to determine the cause of the abnormality. (A) The mean S-T vector is directed approximately + 145° in the frontal plane. Using Grant's method of analysis,[4] let us assume that the mean S-T vector was calculated to be directed about 40° to 45° anteriorly (see text). Such an S-T segment is commonly produced by epicardial injury associated with myocardial infarction. The location of the injured myocardium and the location of the acutely obstructed right coronary artery can be determined by correlating the direction of the mean S-T vector with the anatomy of the heart and coronary arteries. Here, the mean S-T vector is directed toward the inferior portion of the left ventricle and the body of the right ventricle. It also points toward an obstruction in the proximal portion of the right coronary artery that is proximal to its right ventricular branch.
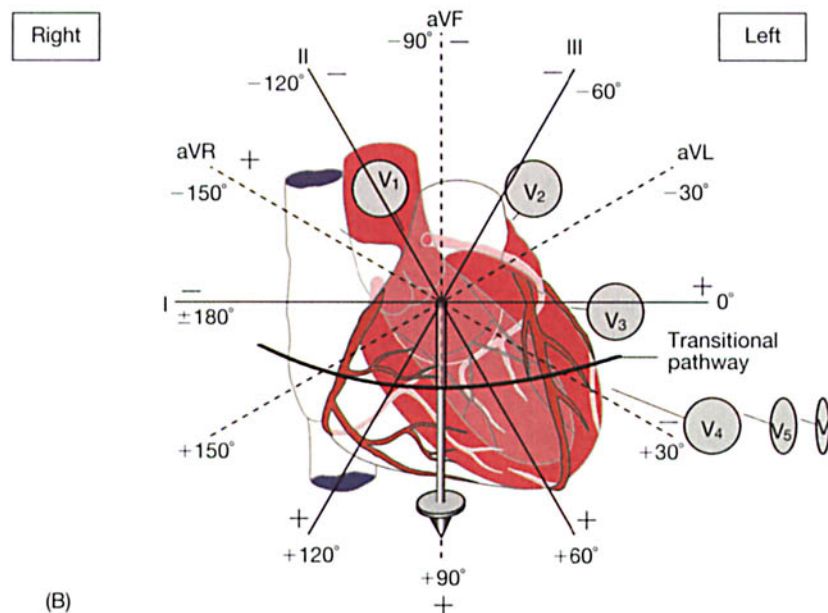

(B)

FIG. 2 (B) The mean S-T vector is directed at + 90° in the frontal plane. Using Grant's method of analysis,[4] let us assume that the mean S-T segment vector was calculated to be directed approximately 30° posteriorly (see text). Such an S-T segment vector is commonly produced by the epicardial injury associated with myocardial infarction. The location of the injured myocardium can be determined by correlating the direction of the mean S-T vector with the anatomy of the heart and coronary arteries. Here, the mean S-T vector is directed toward the damaged myocardium, which is located in the inferior and slightly posterior region of the left ventricle. It also points toward the one or more of the three coronary arteries that perfuse this area of myocardium. The coronary artery obstruction may be in the mid or distal portion of the right coronary artery, the branches of the circumflex coronary artery, or rarely in a "wrap-around" left anterior descending coronary artery.
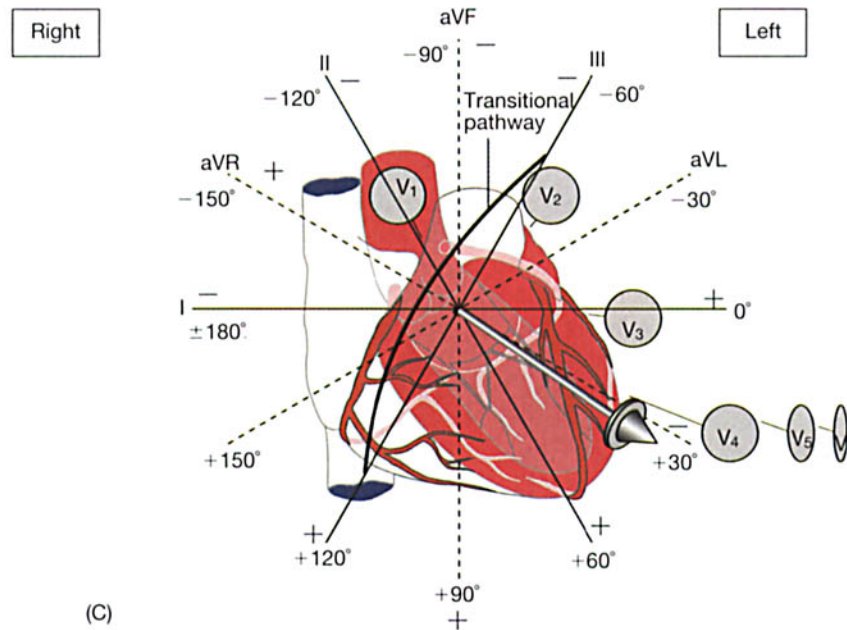
(C)

FIG. 2 (C) The mean S-T vector is directed at + 35° in the frontal plane. Using Grant's method of analysis,[4] let us assume that the mean S-T vector was calculated to be directed approximately 10° anteriorly. Such an S-T segment vector is commonly produced by the epicardial injury associated with generalized pericarditis or uncommonly produced by a myocardial infarction located near the cardiac apex. Pericarditis due to infection is usually generalized and involves the entire pericardium and epicardium. Accordingly, it produces an S-T segment vector that tends to be parallel with the anatomic axis of the heart, whereas an S-T segment displacement produced by the epicardial injury related to myocardial infarction is usually located in a segment of the left ventricle. Therefore, an S-T segment vector due to myocardial infarction is usually directed laterally to the left, anteriorly, inferiorly, posteriorly, or laterally to the right. Epicardial injury caused by an apical infarction is an exception to the general rule just stated; the mean S-T segment abnormality caused by an apical infarction is directed toward the cardiac apex. Therefore, an "apical" infarct may not produce abnormal Q waves because there is no viable myocardium opposite the apex and the direction of the mean S-T vector may simulate the S-T vector of pericarditis because it is also directed toward the apex. An apical infarct may be caused by an obstruction in a diagonal branch of the left anterior descending coronary artery, the obtuse marginal branch of the circumflex coronary artery, or rarely the posterior descending branch of the right coronary artery.

The S-T segment vector is directed toward the epicardial injury associated with infarction of the inferior and posterior portion of the left ventricle.

Such an infarction is usually caused by an abrupt occlusion of the mid or distal portion of the right coronary artery or branches of the circumflex coronary artery. On rare occasion the abnormality can be caused by occlusion of a wrap-around left anterior descending coronary artery.

Figure 2C shows an S-T segment vector directed at + 35° in the frontal plane. This produces an elevation of the S-T segment in leads II, III, and aVF. The S-T segment will also be elevated in lead I, slightly elevated in lead aVL, and displaced downward in lead aVR. As diagrammed, this particular S-T segment will be displaced downward in lead V_1, slightly elevated in lead V_2, and displaced upward in leads V_3–V_6 because the S-T segment vector is directed only about 10° anteriorly.

The S-T segment displacement is produced by epicardial injury and points toward the cardiac apex. Such an S-T vector can be caused by one of two different conditions: the patient could have generalized pericarditis or a myocardial infarction at or near the cardiac apex.

Should an infarction be the cause, the abrupt occlusion may be in a diagonal branch of the left anterior descending coronary artery, the obtuse marginal branch of the circumflex coronary artery, or rarely in the posterior descending branch of the right coronary artery.

The point made in Figure 2A, B, and C is that many individuals who memorize patterns, but do not understand their genesis and do not measure the forces responsible for them, have difficulty detecting the subtle but important differences in the tracings they erroneously believe to be similar.

Commonly Used Basic Electrocardiographic Principles that Should Be Stored in the Brain

Although it sounds paradoxical, the more one uses information the more it is stored in the brain. This applies to commonly used basic principles of electrocardiography, including the use of vector concepts. In a textbook on electrocardiography it does not help if basic principles are discussed in Chapter 1 but are ignored when tracings are interpreted using the pattern method of interpretation in the subsequent chapters of the

book. As Grant and Wilson emphasized, the basic principles must be used in the interpretation of every tracing.[4, 18]

At this writing little can be done but to list the types of basic principles and information that must be stored in the brain. These basic principles can be viewed as images that must be superimposed one on the other (see legend in Fig. 1A). The basic principles are the image of the anatomic position of the four chambers of the heart as viewed in the frontal, left lateral, and transverse planes;* the image of the location of the atrioventricular node, the left conduction system, the septal branch of the left conduction system, the left anterior-superior and left posterior-inferior division branches of the left conduction system, and the right conduction system; the image of the direction of the normal depolarization process of the atria and ventricles; the image of the direction of the normal repolarization process of the atria and ventricles; the image of the anatomic location of the coronary arteries; and the image of the location of the superimposed extremity lead axes and chest lead axes. To restate, all of these images should be superimposed one on top of the other. When the diagnostic cardiac vectors are diagrammed using Grant's method and superimposed on the images listed above, it becomes possible to deduce what anatomic, pathologic, and electrophysiologic phenomena produce the electrical forces responsible for the normal and abnormal waves seen in the ECG. This approach enables the clinician to create a differential diagnosis that lists the cardiac diseases that might cause the abnormal electrical forces.

When the foregoing method of measuring and correlating is understood we can describe ECGs as previous masters said we should—that is, in terms of the direction, size, and polarity of electrical forces as well as the relationship of one electrical force to another.

Recommended Steps for the Interpreter of Electrocardiograms

1. Check to be certain the standardization is correct.
2. Identify the heart rate and rhythm.
3. Measure the P-Q interval, QRS duration, and Q-T interval.
4. Diagram the diagnostic cardiac vectors.[†] They are the mean P vector; a vector representing the first half of the P

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*The anatomy I speak of implies that we must know the position of anatomic parts of the heart, including the conduction system and coronary arteries, as they are located in the chest of the patient when the ECG is being recorded. Stated another way—it is difficult for an individual to study the heart and its parts unless the person knows the exact location of the heart and its parts.

[†]The definitions of the diagnostic cardiac vectors were derived from the study of vectorcardiograms. All parts of the P, QRS, and T loops are not always used in electrocardiographic diagnosis. The designated diagnostic cardiac vectors are the parts of the loops commonly used in electrocardiographic diagnosis.

wave, which represents right atrial depolarization; a vector representing the second half of the P wave, which represents left atrial depolarization; the mean QRS vector, a vector representing the first 0.01 s of the QRS complex, which represents depolarization of a large middle portion of the left ventricular side of the interventricular septum; a vector representing the first 0.03 to 0.04 s of the QRS complex, which normally represents endocardial depolarization of both ventricles; a vector representing the next 0.03 to 0.04 s of the QRS, which represents depolarization of the posterior portion of the left ventricle; a vector representing the last 0.01 s of the QRS, which represents depolarization of the superior portion of the left ventricle (which is located posterior to the cardiac apex); the mean S-T vector; and the mean T vector. In addition, it is necessary to search the tracing for an abnormal P-Q segment, delta waves, epsilon waves, Osborn waves, other J deflection waves, Bruguda waves, and U waves.

5. Determine whether the electrical forces represented as vectors fall into the normal or abnormal range. This requires a knowledge of the normal direction, normal size, and the normal relationship of each diagnostic cardiac vector to other cardiac vectors.

6. If the vectors are abnormal, create an anatomic-electrical differential diagnosis. An example would be to conclude that there is complicated right bundle-branch block plus left anterior superior division block (RBBB + LASDR).

7. The clinician should then create a differential diagnosis as to the disease processes that could produce the anatomic-electrical differential diagnosis. For example, if RBBB + LASDB is present, the differential diagnosis of disease processes would include multiple myocardial infarcts (usually due to coronary atherosclerotic heart disease), dilated cardiomyopathy, ostium primum atrial septal defect, severe long-standing multivalvular disease, primary disease of the conduction system, surgical severance of parts of the conduction system, and rarely hyperkalemia.

8. Finally, and most important, the ECG diagnosis must be correlated with the other information collected from the patient. This is absolutely necessary because information other than that provided by the ECG is commonly needed by the clinician for selecting the proper diagnosis from a list of possible diagnoses determined by the interpretation of the ECG. As time passes and the proper experience is gained, the correlator can determine whether the ECG findings "fit" the rest of the clinical picture, or whether they indicate the presence of a cardiac disease that is unrelated to the other clinical data collected from the patient. Finally, the physician who correlates information gradually enlarges his or her list of cardiac etiologies suggested by the ECG interpretation.

Conclusions

Memorizing abstract signals, such as the shape of the complexes seen in ECGs, and associating them with disease processes has its limitations and is difficult to teach. The basic explanation for this difficulty lies in the understanding of mem-

ory, thinking, and learning. It all adds up to the fact that memorizing without understanding is not the best way to learn.

This essay is obviously incomplete because the limitation of space does not permit a detailed discussion of the basic principles, including an in-depth discussion of vector concepts, that should be understood in order to interpret ECGs. Most important, Grant's method of simply inspecting an ECG and diagramming the spatial direction of the electrical forces that produce the deflections is not discussed. These principles and Grant's method of interpretation are to be found in the books and articles identified in the references.[1-8] Central to the discussion, however, is that commonly used basic principles, which include the use of diagnostic cardiac vectors, should be used to interpret every tracing.

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